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Biology and Control of the EUROPEAN PINE SHOOT MOTH

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THE BIOLOGY AND CONTROL OF THE EUROPEAN PINE SHOOT MOTH

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INTRODUCTION

At the present time, the European pine shoot moth, *Rhyacionia buoliana* (Schiffermüller)[3], is the prime insect menace to reforestation and Christmas tree growing in a large part of Ohio. Because of this pest, the planting of red or Norway pine, *Pinus resinosa* Aiton, has become a hazardous silvicultural venture, and less desirable trees are being used.

The injury inflicted by the shoot moth is the severing of needles and the tunneling of buds and shoots. Bud and shoot injury inhibits growth and causes deformation of trees. Rarely, if ever, are trees killed by the shoot moth.

This paper presents the results of laboratory and field studies made in Ohio during the four seasons from 1950 through 1953. Reviews of previous literature are contained in the papers by Butovitsch (1936), Friend and West (1933), and Brooks and Brown (1936).

HISTORY AND DISTRIBUTION IN OHIO

The insect was first discovered in Ohio in 1915, shortly after its first recorded appearance in the United States on Long Island (Busck, 1915). Immediate steps were taken to eradicate this early infestation which occurred in a nursery in the middle eastern part of the state (Harrison County). For the next 13 years, if the pest was present in Ohio, it attracted no attention for it is not mentioned again in the available records[4] until 1928. In that year J. S. Houser diagnosed injury to pines near Cleveland as probably caused by the European pine shoot moth and in the following year the insect was positively identified from that area. By about 1940 it was present throughout the northern part of the state (Paton *et al.*, 1944).

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In 1950 a survey[5] was carried out to establish the exact geographic range of the shoot moth in Ohio. Accordingly, red pine plantations in 137 townships in 23 counties were examined. The survey showed that the shoot moth was present in Ohio throughout the area from Lake Erie south to the 40th parallel (Figure 1). The majority of the infestations were encountered in the eastern half of this area where pine plantations according to Paton *et al.* (1944) are correspondingly larger and more numerous.

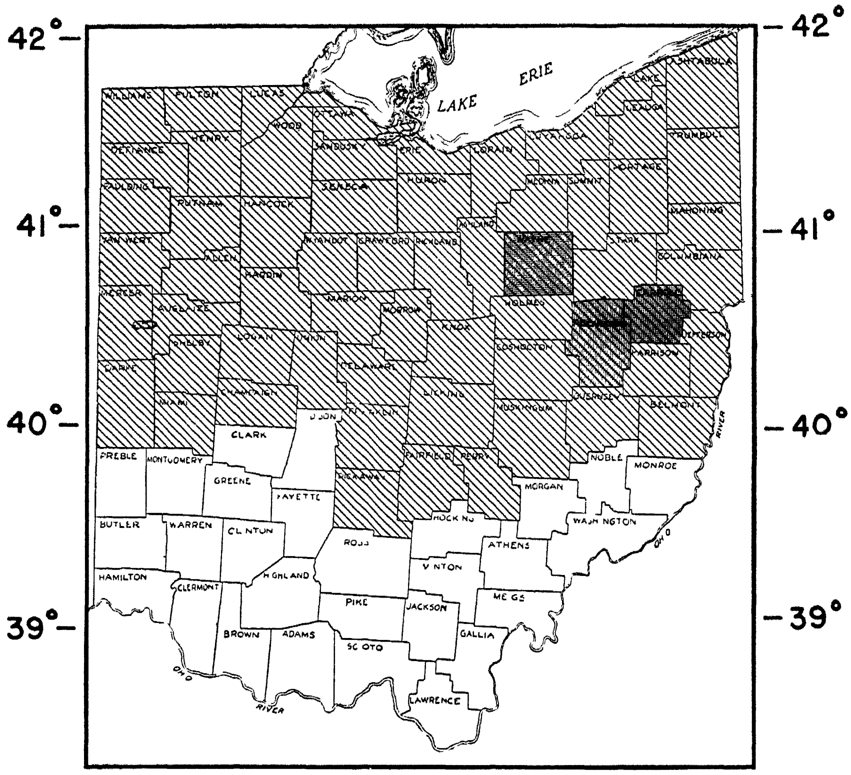

Fig. 1.—Range of the European pine shoot moth in Ohio by counties. Cross hatching shows range; dark shading shows counties in which the field studies were conducted (from left to right Wayne, Tuscarawas, and Carroll).

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[5]McElroy, J. R. 1950. Survey of European pine shoot moth damage to red pine plantations in Ohio. Ohio Division of Forestry. Unpublished.

HOSTS AND NATURE OF INJURY

The species commonly found as hosts of the shoot moth in Ohio are red pine, Swiss mountain pine, *Pinus mugo* Turra, and Scotch pine, *P. sylvestris* Linnaeus. White pine, *P. strobus* Linnaeus, has been found infested occasionally when growing near severely infested red and Scotch pine trees. However, the insect was observed to complete its development only in unusually vigorous shoots of this species.

Newly hatched shoot moth larvae bore into and feed within current growth needle sheaths. Needle damage is most conspicuous in late summer. At this time, needles that were attacked are brown and dislodged, and they hang haphazardly about the trees. As the larvae grow they move to buds which they partially or totally hollow out. Injury to buds can usually be observed beginning the second week after hatching, and the number of buds injured increases thereafter until the onset of cool weather. During the summer a single larva may feed in more than one bud.

In the spring when the overwintred larvae resume their feeding, new buds and elongating shoots are bored into and tunnelled. At this season also, more than one bud or shoot may be fed upon by a single larva. The most important and permanent damage to trees results from the spring activity of the shoot moth. When shoots weakened by tunnelling fall over, yet continue to grow from the fallen position, crooked trunks and branches, or "posthorns", are formed. Adventitious buds frequently develop on tips severely injured in summer, giving rise the following season to the dense growths commonly called "bushy tips". Where infested trees are not growing vigorously because of other reasons, tips may not recover from a severe shoot moth attack, and dead, barren tips, or "spike tops", are the result.

The publications by Butovitsch (1936), Friend and West (1933), and Brooks and Brown (1936) should be consulted for more detailed discussions of hosts and damage with illustrations.

SEASONAL HISTORY

Seasonal history information was obtained from five infested plantations in Wayne, Carroll, and Tuscarawas Counties (Figure 1).

One generation of the European pine shoot moth develops annually. The eggs are deposited from the middle of June to the middle of July. The first signs of larval activity by the new generation can be seen the last week in June. The winter is spent primarily in the fourth larval instar.

Larval activity the following spring is resumed about the middle of April. Pupation takes place within the larval tunnels beginning the latter part of May and becoming complete by the middle of June. The moths are present for about a month, first appearing during the second week in June. The dates of the preceding events vary somewhat from year to year depending upon environmental factors.

Friend and West (1933) have described in detail and illustrated all life stages of the insect.

OVIPOSITION AND INCUBATION. Fifty-four eggs found at various times in the field had been deposited on current growth needles (Figure 2), needle sheaths, and stems. These eggs occurred both singly and in masses, with up to five overlapping eggs comprising a mass.

In the Experiment Station insectary (Wayne County), oviposition by mated females usually began within 24 hours after emergence (Table 1). Six mated females deposited from 92 to 258 eggs, averaging 168 per female. These eggs were deposited indescriminately on any type of available surface. Of the resulting 1,008 eggs, 85 percent hatched, with hatching percentages varying from 67 to 97 for individual females. These female moths therefore produced an average of 143 larvae per female. Near the end of oviposition activity, the moths tended to deposit all eggs singly and a higher percentage of such eggs failed to hatch.

As indicated previously, a total of 54 eggs were observed where they were deposited normally in a forest planting. Fifty-three or 98 percent of these eggs hatched.

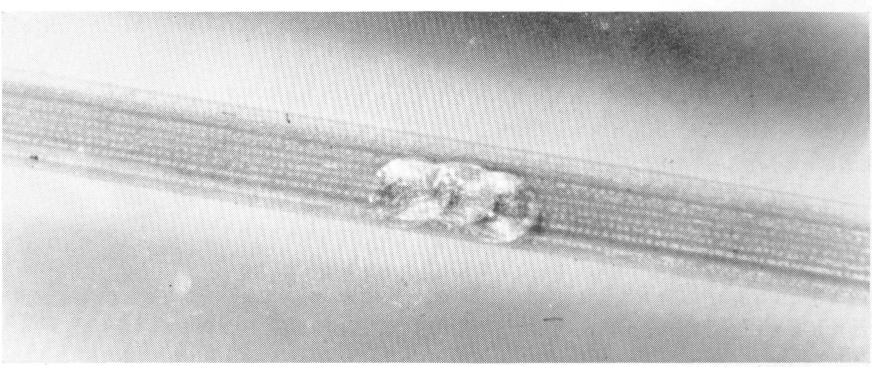

Fig. 2.—Eggs on a red pine needle from which larvae had recently hatched. All eggs found on needles were located on the flat side.

Of the many eggs obtained in the insectary, 8 lots (total of 177 eggs) were deposited and also hatched within 24-hour periods, and thus gave clear-cut periods of incubation. As determined from these lots of eggs (between June 20 and July 8, 1951), the incubation period averaged nine days, and varied from eight to ten days.

The combined duration of preoviposition and incubation periods as determined in the insectary (mean of 10 days) does not equal the duration of the same periods as observed in nature (mean of 19 days). Even with an allowance for observational error, this discrepancy of nine days probably represents a real difference. Males are known to issue in advance of females, and thus egg laying is delayed in relation to total emergence. Also, DeGryse (1932) has found a longer than average incubation period in Ontario during the first part of the egg deposition period which he attributes to lower natural temperatures at that time.

LARVAL STAGE. The approximate date of incipient hatching for four seasons as determined from field observations on one infestation each season are as follows: June 29, 1950; June 27, 1951; June 26, 1952; July 1, 1953. The activity and habits of the emergent larva have been adequately described by DeGryse (1932), but a review is given below because of the significance of this early activity to chemical control procedure.

After eclosion from the egg, the caterpillar wanders about over the shoot for several hours. It finally settles in the axil of a needle bundle and proceeds to spin a silken tube or tent-like structure between the lower

TABLE 1.—Preoviposition, oviposition, and postoviposition periods of mated and unmated female moths

Period	No. Individuals Observed	Duration in Calendar Days		
		Min.	Max.	Mean
Preoviposition				
Mated females	7	1	2	1.3
Unmated females	16	2	7	3.5
Oviposition				
Mated females	6	4	10	8.0
Unmated females	5	4	6	5.0
Postoviposition				
Mated females	6	0	6	3.4
Unmated females	5	1	4	2.4

part of the needle sheath and the stem (illustrated in the paper by DeGryse). This and similar structures spun by caterpillars at successive stages of development will be referred to as "tents". The initial tent is narrowest at its point of attachment to the needle sheath and widens gradually toward the other end. It is not more than 2 or 3 mm. in length. As soon as the tent is completed, the larva begins to bore its way through the sheath to the needles. The frass is pushed into the tent enclosed area and occasionally is carried by the larva between its mandibles to the opening at the lower end. The entire first instar is spent in this manner.

The second instar larva continues to feed for a time on the needles, but before long it constructs another tent similar in design to the first, but larger in size. This tent is attached to a bud (Figure 3), and when it is completed, the larva bores into the bud at an enclosed point. Resin exuding from the excavation within the bud, as well as frass and other debris, are continuously removed by the larva and either placed somewhere on the tent or dropped outside of it. Resin becomes the predominant component of these deposits and in early stages causes them to glisten in the sunlight. Ultimately, however, the resin hardens and forms yellow-white pitch masses. The term "resin exudate" is used in other sections of this paper to designate these deposits in all stages of development beyond the tent.

Number of Instars. An attempt was made to determine the number and seasonal occurrence of larval instars. A total of 778 caterpillars were collected at intervals averaging six days throughout two larval developmental periods. These larvae were killed in K. A. A. D. larval killing mixture (Peterson, 1949), then stored in 95 percent alcohol until used. The dorsal aspect of the head capsule of each larva was measured to the nearest .01 mm., and a frequency distribution of the measurements was plotted (Figure 4).

Five groups of headwidths were readily distinguished by simple inspection. The middle group actually comprised two groups, however, because larvae in the first half of this large group occurred earlier in the season than did those in the second half. Hence a total of six groups was distinguished. This fact strongly suggests the occurrence of six instars.

Dyar's (1890) method was applied to the headwidth data, but the mean headwidth values for the six groups in the distribution deviated radically from the means calculated according to Dyar's theory. Beck (1950) has recently concluded from experiments with European corn borer larvae, and from data accumulated by other workers for other lepidopterous insects, that Dyar's theory has no fundamental basis, and

Fig. 3.—A tent spun on a bud by a recently hatched larva.

therefore is not a reliable tool. Direct observation of the number of molts seems to be the only reliable means of determining number of instars. Six instars for the European pine shoot moth therefore must be regarded as provisional.

Data on head widths presented by Friend and West (1933) for Connesticut are similar to those given here.

The seasonal occurrence of the larvae comprising each of the six provisional instars was determined from collection dates. Larvae of the first instar were present from hatching throughout most of July. Second instar larvae appeared the first week in July, and by the end of July were no longer found. Most third instar larvae occurred from the second week in July through the first week in August, but some were present in winter collections. Fourth instar larvae were encountered in August and throughout winter and early spring to the end of April, whcn larvae of the fifth instar began to appear. By the second week in May sixth instar larvae were commonly found, and by the third week in May they predominated.

Hibernation and Mortality. Throughout the winters of 1950-51 and 1951-52 red pine tips were collected at three-week intervals from a plantation in Wayne County, and the larvae dissected out and examined. Of 968 larvae found, 49 percent were beneath hardened resin exudates on the outside of buds, and 51 percent were within buds. No relation between place of hibernation and degree of winter mortality was apparent.

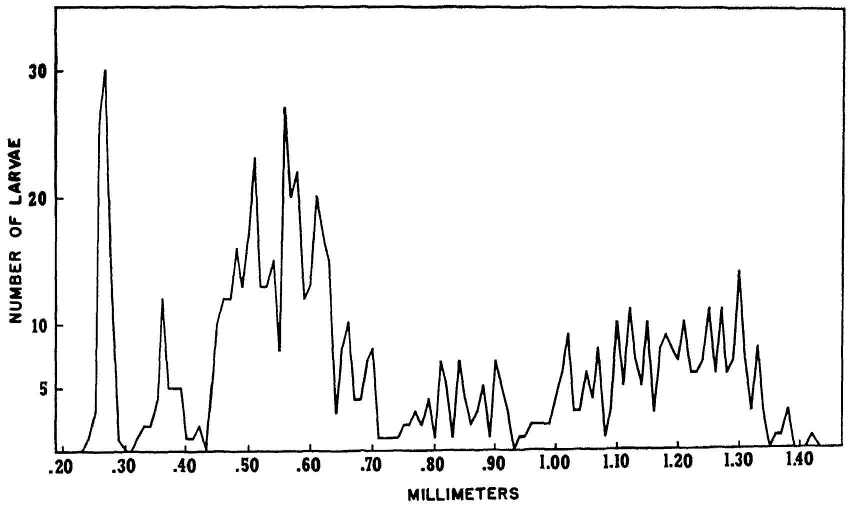

Fig. 4.—Frequency distribution of larval head capsule measurements.

The mean number of living larvae per injured tip was plotted on different dates through each winter for the Wayne County plantation. These data (Figure 5) show declines of 65 and 75 percent in living larvae between October-November and April. Approximations of the total mortality occurring at the plantation in Tuscarawas County through much of the same period are seen in table 2 to average 64 percent. Mortality of the larvae was also high prior to cold weather. In 1952 untreated trees were examined at 5 to 7 day intervals for the presence of fresh resin exudates caused by newly hatched larvae. None were found on June 18 or June 24, but on July 1 an average of 12.2 per tree was recorded. The number per tree increased during the three succeeding weeks and on July 21 reached an average of 105.6. Between July 21 and a date 5 or 6 weeks later when counts were made to determine the effectiveness of the insecticidal treatments (Table 8), the number of fresh resin exudates on untreated trees decreased by 84 percent. On the other hand, natural mortality observed in nearly full grown larvae and pupae that were encountered during the spring never exceeded 13 percent. Where possible, parasitization was excluded from all these mortality data. However, it is very doubtful if parasitization in any instance made up a significant proportion of this mortality.

A similar pattern and similar magnitudes of mortality have been recorded by previous investigators in other areas (Friend and West, 1933; West, 1936; Friend *et al.,* 1938 in Connecticut; and Schaffner, 1948[6] in New York).

Temperatures sufficiently low to kill an unusually high percentage of hibernating larvae may have occurred locally in northeastern Ohio during the winter of 1950-51. The infestation over the region was reported to be less severe the following spring. However, it has since built up to its former proportions if in fact there was any reduction. West's (1936) conclusion that " low winter temperatures such as sometimes occur in Connecticut temporarily depress the shoot moth population, but do not necessarily eliminate the insect" undoubtedly holds for Ohio also.

Larval Activity in the Spring. Prior to entering a new bud in the spring, the caterpillar spins a tent in much the same manner as the newly hatched larva. The spring tent is built between the bud to be excavated and one or more adjacent buds or needles (Figure 6). Upon completion

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[6]Schaffner, J. V., Jr. 1948. Data on the mortality of the hibernating larvae of the European pine shoot moth in New York during the winter of 1947-48. Unpublished

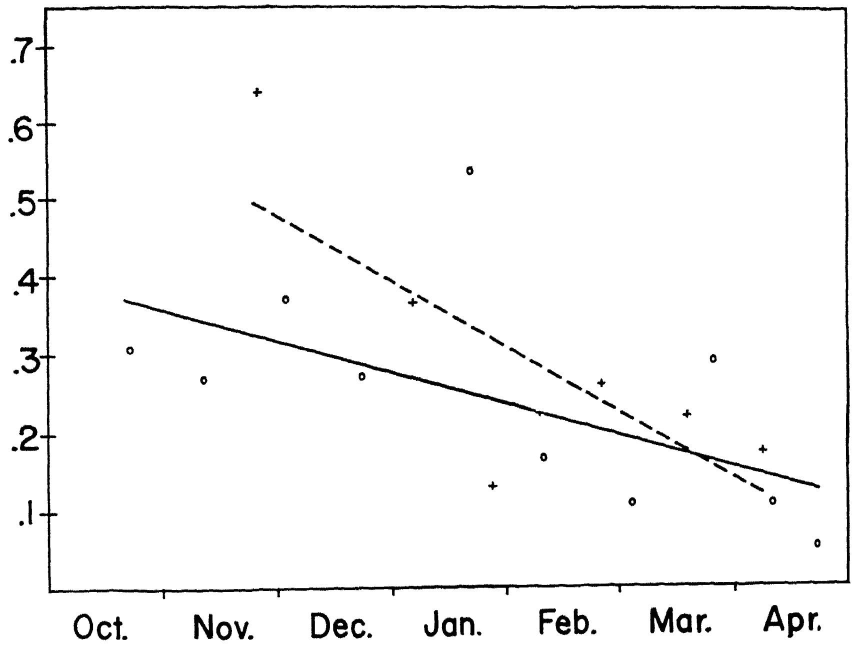

Fig. 5.—Mean number of living larvae per infested tip through the cold season in an infestation in Wayne County. Solid line represents 1950-51, broken line 1951-52.

of the tent, the larva bores its way into the bud at a point within the enclosure. The structure is thereafter used as a depository for much of the resin, frass, and other debris accumulating in the feeding chamber. The resin is carried to position as tiny droplets between the larva's mandibles while other objects are either carried or pushed. These materials are placed along with strands of silk on the interior surface of the tent

TABLE 2.—Mortality between August 1951 and May 1952 in the 1951 test plots (Tuscarawas County)

Mean No. Resin Exudates per Tree in August 1951	Mean No. Living Individuals per Tree in May 1952	Approximate Percentage Mortality
.9 (DDT treated)	.4	61
3.2 (Parathion treated)	1 1	67
101 7 (Check—no treatment)	35 9	65

and in nooks and corners in the enclosed area. Some waste material is dropped outside the tent. The fresh resin causes the tent to glisten in the sunlight during April and May. As larval activity progresses, the resin deposit increases in overall size and thickness and ultimately solidifies, forming a yellow white mass.

The approximate dates of incipient external spring activity in 1951, 1952, and 1953 as determined by observations in one infested plantation each year are April 20, April 15, and April 13, respectively.

The activity in early spring (Figure 6) is very similar to that immediately following hatching (Figure 3). This similarity suggested that early spring might be a second period of vulnerability to insecticides in the life of the shoot moth. Experiments to test this possibility were carried out and are treated in a later section.

PUPAL STAGE. Pupation was found to take place almost always within the larval burrow. In severe infestations, some larvae pupated on the outside of shoots beneath hardened resin exudates. The length of the pupal stage is estimated to be 16 days from the field observations on pupation and emergence presented in Table 4. Friend and West (1933) reported the average pupal period in Connecticut to be 17.7 days for males and 18.5 days for females.

EMERGENCE AND ADULT STAGE. Emergence records during the first three seasons of the study were obtained from caged shoots collected each season at three or more localities and in two or more counties. Several hundred shoots represented each locality in these collections. So little variation among localities in date of initial emergence was recorded during these three seasons (maximum of four days), that only 100 shoots from only one locality were collected the fourth season. The four-year record of initial insectary emergence dates is as follows: June 12, 1950; June 6, 1951; June 8, 1952; and June 11, 1953. The dates of peak and final emergence can be seen in Figure 7 which graphically presents insectary emergence data.

In giving the dates of initial issue of moths in the insectary, it should be mentioned that emergence in the insectary lagged somewhat behind that in the field. From Table 3 in which insectary and field emergence are compared, the lag is estimated to have amounted at first to two days. It increased somewhat as the period progressed, for natural emergence was complete after about four weeks while insectary emergence required about five weeks for completion. On the average, shoots had been in the insectary less than a week when emergence began.

Emergence of females lagged somewhat behind that of males. The sex ratio was approximately 1:1. Mating in the insectary took place within 24 hours after emergence. Copulation was never observed earlier than 8:00 p.m. E. S. T., and approaching midnight the number of copulating pairs always declined.

Fig. 6.—A tent spun to a bud by a larva in the early spring.

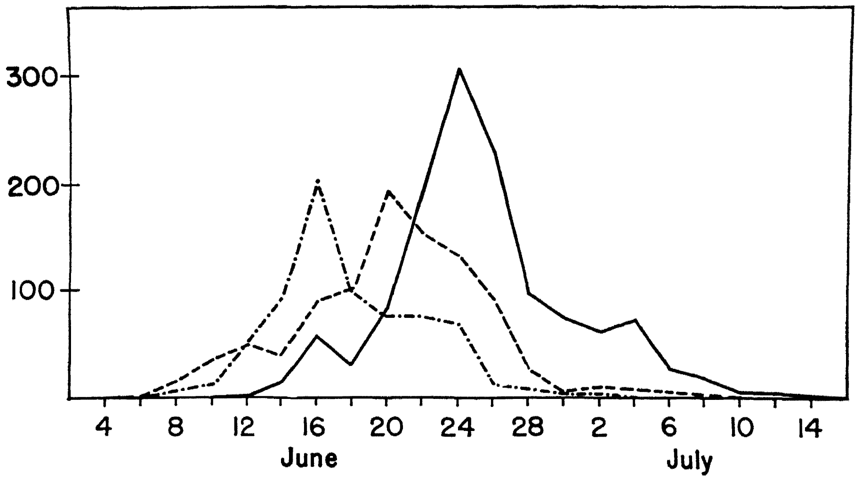

Fig. 7.—Record of moth emergence in the insectary. Solid line represents 1950, broken line 1951, and dot-dash line 1952.

The size of cage used to hold moths in the insectary had considerable effect on mating activity. Two types of small cages were designed for use as mating cages, but out of 70 trials with these cages, only one female produced fertile eggs. One type of small cage consisted of a glass fruit jar with a wire gauze lid, and the other of a glass tube 9 inches long and 1½ inches in diameter with muslin-covered ends. The volumes of these cages were 30 and 17 cu. in. respectively. Newly emerged moths in single and multiple pairs were placed in these cages, some with freshly cut red pine shoots. The cages in which mating activity took place uninhibited were the large cages designed originally for emergence purposes. These cages consisted of wooden rectangular or cylindrical frames covered either with muslin or plastic screen. The shortest dimension of either type was 12 inches, and their volumes were approximately 2 cu. ft. Copulating pairs were encountered in these cages whenever newly emerged individuals were left in them until evening. Up to five pairs per cage were found *in copula* at one time.

Data concerning oviposition have been summarized in Table 1. Mating apparently acted as a stimulus to oviposition because the length of the preoviposition period of mated females averaged one-third that of unmated females, and mated females oviposited over a longer period of time than did unmated ones.

The length of life of 41 male and 43 female adults was determined. Small groups of the moths were placed in fruit jars without food or water. The males lived from 3 to 14 days, averaging 7 days, while the females lived from 4 to 18 days, averaging 11 days.

TABLE 3.—Pupation and emergence records

Date		No. Individuals Observed (Field)	Percentage Pupation (Field)	Percentage Emergence	
				Field	Insectary
		1950			
May	21 22	84	1	——	——
	25	36	8	——	——
June	2	70	64	——	——
	7	59	83	0	——
	12-13	87	94	2	0
	19-20	98	100	30	14
	28	32	——	94	79
July	2	36	——	97	91
		1951			
May	29	29	35	——	——
June	1	38	58	0	0
	6-8	33	84	3	2
	14	71	90	27	10
	19	44	79	63	43
	22	68	100	84	70
	25	95	——	97	89
	29	41	——	100	97
		1952			
May	8	42	0	——	——
	22	97	12	——	——
	28	113	80	——	——
	31	68	65	——	——
June	5	90	93	0	0
	13	82	100	19	14
	18	72	99	49	65
July	1	50	100	100	100

PARASITIZATION

Two different parasite associations were found developing on the shoot moth, one during the summer while the larvae were small and the other in the spring when the larvae were completing their development and pupating. Friend and West (1933) reported that the eggs were attacked by *Trichogramma minutum* Riley in Connecticut, but no evidence of egg parasitization has been found in Ohio.

Colonies of *Hyssopus thymus* Girault (Eulophidae) and of two species of *Goniozus* (Bethylidae) parasitized the young larvae in the summer and remained in the larval tunnels through the winter. Of the total of 405 injured tips examined from an infestation in Wayne County during the winter of 1951-52, 8 percent contained one or more parasite colonies. Colonies of *Hyssopus* and *Goniozus* occurred in about equal numbers. *Goniozus* was represented by *G. nr. electus* Fouts and a single specimen of *G. columbianus* Ashmead. The number of individuals per colony averaged 2.4 for *Hyssopus thymus* (Miller, 1953), and 1.4 for *Goniozus,* varying in the latter between 1 and 4. *Goniozus* individuals were observed to be in the adult stage during the autumn and winter. Only females were recovered, and the majority of these were dead when found.

During the spring, the principal parasites attacking the maturing larvae were *Calliephialtes comstockii* (Cresson) (Ichneumonidae), *Eurytoma tylodermatis* (Ashmead) (Eurytomidae) and *Hyssopus thymus.* Representatives of ten other parasitoid species appeared from time to time in the emergence cages, but of these only *Itoplectis conquisitor* (Say) (Ichneumonidae), which emerged from the pupa, is known by direct observation to have developed on the shoot moth. The species of unverified status are *Bracon gelechiae* Ashmead, *B. politiventris* (Cushman) (Braconidae), *Goniozus columbianus, G. foveolatus* Ashmead (Bethylidae), *Dibrachys cavus* (Walker), *Hypsicera* nr. *femoralis* (Fourcroy), *Scambus hispae* (Harris), *Syrphoctonus agilis* (Cresson) (Ichneumonidae), and *Habrocytus thyridopterigis* Howard (Pteromalidae).

The principal spring parasites are solitary in their development with the exception of *Hyssopus thymus.* The number of individuals of this species developing on a single host larva in the spring averaged 11.8 (Miller, 1953). Additional information on the biology of the three most common shoot moth parasites in Ohio can be found in the paper by Miller (1953).

Quantitative data on spring parasitization are given in Table 4. The total spring parasitization observed for all localities during the three-year period from 1950 through 1952 amounted to approximately 8 percent. The highest rate of parasitization found in material from any one infested plantation in any one year was 17 percent, and the lowest was 5 percent. Not represented in these figures, however, is an additional generation of *Hyssopus thymus* that develops on late-maturing larvae. This generation was absent in the insectary because shoots were brought in before its normal occurrence. The late season field observations in 1951 and 1952 revealed parasitization rates of 2 and 7 percent respectively, by this generation.

In emergence cages one or more undetermined species of Attid spiders preyed upon the adult moths. These spiders are normally associated with red pine trees and were introduced into the cages incidentally with the infested shoots.

Hyssopus thymus, Calliephialtes comstockii and *Eurytoma tylodermatis* have been reported parasitizing the shoot moth at other places in the United States and Canada (Friend and West, 1933; Friend and Hicock, 1936; Friend *et al.* 1938; Mathers and Olds, 1940), but neither these nor other native parasites have ever been reported as significantly reducing shoot moth populations.

Several European parasites of the pest have been introduced into New England and southern Ontario (Berry, 1939; Dowden, 1934; Dowden and Berry, 1938; Marlatt, 1933; Sheppard, 1929; Strong, 1937; and Thorpe, 1930), but none of these were encountered in Ohio.

TABLE 4.—Spring parasitization of the shoot moth determined from insectary emergence records

Species	Total Emergence					
	1950		1951		1952	
	No.	Percent	No.	Percent	No.	Percent
Host	1256	92	939	91	696	92
Calliephialtes comstockii	44	3	32	3	42	5
Eurytoma tylodermatis	46	4	58	5	16	2
Other parasites*	16†	1	6†	1	7†	1
Total parasitization		8	——	9	——	8

*Includes those species not known by direct observation to parasitize the shoot moth.

†Where the gregarious parasite *Hyssopus thymus* was involved, ten individuals were considered to represent one parasitized shoot moth in accordance with information given by Miller (1953).

OTHER PINE MOTHS IN OHIO

Several pine moths indigenous to Ohio have habits similar to the European pine shoot moth, and it is possible that at times the injury caused by these moths might be mistaken for that of the shoot moth. The larvae of *Rhyacionia rigidana* (Fernald) burrow into needle bases, buds, and shoots, but unlike shoot moth larvae, they usually occur gregariously within a shoot. Two generations of *R. rigidana* are produced annually in Ohio, the adults being present in April and again in July. Larvae of the pitch nodule makers, *Petrova* spp. (Olethreutidae), in their early instars also bore into needle bases. In later instars, however, their work becomes more distinctive, a large hollow nodule of frass and resin being formed by each larva. The larvae of the Zimmerman pine moth, *Dioryctria zimmermani* (Grote) (Phycitidae), often bore into shoots of pine, but they may also tunnel beneath the bark of the trunk and large branches. Shoot injury caused by the Zimmerman moth can be distinguished from shoot moth injury by the presence of coarse globules of frass mixed with resin which are extruded by the Zimmerman larva at intervals along the length of the shoot. No such globules are formed by shoot moth larvae.

In Ohio, knowledge of the distribution of the several species is often the simplest and most useful means of differentiating the work of native moths from that of the shoot moth. The distribution of the native *Rhyacionia rigidana, Petrova comstockiana* (Fernald), *P. virginiana* (Busck), and an undescribed species of *Petrova* corresponds to the distribution of the three southern pines native to Ohio, namely pitch, *Pinus rigida* Miller; scrub, *P. virginiana* Miller; and shortleaf, *P. echinata* Miller. None of these pines, and none of the moths occur extensively above the 40th parallel. The European pine shoot moth on the other hand does not occur below the 40th parallel as was shown in an earlier section. The ranges of the four native moths just named therefore are separate and distinct from the range of the shoot moth. The Zimmerman pine moth, however, occurs throughout the state.

CONTROL EXPERIMENTS WITH SYNTHETIC ORGANIC INSECTICIDES

Because of the inadequate amount of information available dealing with synthetic organic insecticides as control materials for the shoot moth, these newer chemicals were employed almost exclusively in the control portion of the study. Control experiments were conducted during four growth seasons, from 1950 through 1953. Applications were made during two phases of the insect's life: the period of hatching (June-July) and the period of early spring activity (April).

PREVIOUS EXPERIMENTAL WORK. The first published account of a synthetic organic insecticide being used against the shoot moth is that of Zappe and Plumb (Friend, 1945) in Connecticut. An unsuccessful attempt at control was made with a helicopter from which a spray mixture containing 12.5 percent DDT was dispersed at the rate of 1 pound of actual DDT to the acre. This treatment was applied on June 21, during the moth flight period.

In New York, Potts and McIntyre[7] obtained a high degree of control with single and dual spray and mist applications of DDT. This toxicant was used in spray form at the rate of approximately 2 pounds in 100 gallons and in mist form at approximately 20 pounds to the acre. The single and dual sprays resulted in 2 and 0 percent infested tips respectively, per 8-foot tree; the single and dual mists, 3 and 9 percent. Treatments were applied June 28-29, and July 10.

In Delaware, Stearns (1953) obtained complete control with each of three materials applied in triple high volume spray applications. The materials were DDT (1 lb. 50% WP in 50 gals.), parathion (10 ozs. 25% WP in 50 gals.) and BHC (1½ lbs. 6% gamma in 50 gals.). The first application was made when moths commenced emerging, the second on the date of maximum emergence, and the third on the date of final emergence.

EXPERIMENTAL PROCEDURE. In 1950, 1952, and 1953, insecticide plots were located in a plantation in Carroll County, while in 1951 they were located in a plantation in Tuscarawas County. Plot trees varied in height from a little more than two and one-half feet to eight feet, but in a particular experiment tree size was fairly uniform.

In 1950, plots in which ground equipment was used consisted of blocks of nine trees, with the population samples being taken from the central five trees. In experiments after 1950, plot size was reduced to four trees with each tree being sampled. All ground applied treatments were replicated five times. In the airplane treatments, ten-acre blocks of trees were treated, with five five-tree sub-sample plots being selected at random for population counts in 1950, and five four-tree sub-sample plots in 1951 and 1953.

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[7]Potts, S. F., and Thomas McIntyre. 1950. Spray tests for control of the European pine shoot moth. Unpublished.

High volume sprays were applied with a power sprayer at pressures between 200 and 300 pounds per square inch. The foliage was thoroughly wetted in such treatments; one-half gallon of mixture was sprayed per tree on trees three feet high, and a gallon on trees six feet high. At this delivery rate, .01 and .02 pounds of actual DDT was used per six-foot tree respectively, at 1 and 2 pounds of the toxicant in 100 gallons of water.

Low volume sprays were applied with a knapsack sprayer and by airplane. In the 1950 and 1951 treatments (summer), the knapsack sprayer was operated at a pressure of 25 pounds per square inch and was equipped with a cone type nozzle (aperture diameter of 1/32 inch) that produced a fine mist-like spray. The foliage was not thoroughly wetted in this type of application; slightly less than one-half fluid ounce of spray mixture (approximately one gram of actual DDT) was applied per tree to trees six feet high. In the 1953 knapsack sprayer test (spring), a cone type nozzle (aperture diameter of 3/64 inch) was used which produced larger spray droplets. This nozzle allowed the foliage to be thoroughly wetted. The volume of spray mixture delivered averaged one pint (two grams of actual DDT) per three-foot tree. In both the airplane spray treatments, five gallons of the spray mixture (1.3 pounds of actual DDT; .4 pound of actual parathion) were delivered per acre. The foliage was not thoroughly wetted by this quantity of mixture.

Dusts were applied with a rotary hand duster and by airplane. The dusts put on with the hand duster were applied on trees six feet high at the average rate of one and one-half ounces per tree (2 grams of toxicant in 5% DDT dust). Dust was dispersed by airplane at 30 pounds (1.2 pounds of actual DDT) to the acre. The garden aerosol was released at the rate of slightly less than one-half ounce per six-foot tree.

Results of summer treatments are presented in terms of the mean number of tips infested per test tree. Results of spring treatments are expressed in terms of the mean number of insects present (larvae and pupae, including those parasitized) per test tree. The counts were made from four to six weeks after treatments were applied. Infested tips in summer treatments were easily detected in late August and September by the presence of fresh resin exudates about the buds. In the spring, buds and shoots containing larvae and pupae were detected again by resin exudates, and by injury symptoms.

RESULTS OF SUMMER APPLICATIONS. From Tables 5, 6, and 7, which contain results of summer applications, it can be seen that DDT and parathion consistently gave the best control. The data show also that, in general, sprays were more effective than dusts, and that high volume sprays applied with power ground equipment gave better control than low volume sprays applied manually or by airplane.

Optimum Time For Summer Applications. In 1951 and 1952 experiments were carried out to determine the optimum time (with respect to hatching) for applying a single spray. Identical high volume DDT mixtures were sprayed on trees in different plots at approximately five-day intervals beginning in the early part of the moth flight period. These applications continued until hatching was completed.

TABLE 5.—Comparative effectiveness of different treatments applied in summer (1950). Initial and single applications were made July 3-6; second applications followed one week later

Materials and Formulations	Type of Applicator	No. Applications	No. Infested Tips per Tree Following Treatment			Percentage Control
			Min.	Max.	Mean	
DDT, 50% WP 4 lbs. in 100 gals.	Power sprayer	2	0	4	.4	99
DDT, 25% Emul., 400 ml. in 3 gals. . . .	Knapsack sprayer	2	0	32	6.4	92
DDT, 5% dust	Rotary duster	1	3	47	15.8	80
DDT, 5% dust	Rotary duster	2	0	72	16.5	76
DDT, 4% dust	Airplane	1	7	160	49.0	37
Parathion, 15% 2 lbs. in 100 gals. . . .	Power sprayer	1	0	35	2.8	96
Parathion, 1% dust	Rotary duster	2	0	25	8.4	89
Parathion, 1% dust	Rotary duster	1	0	34	14.2	82
EPN, 27% WP, 1½ lbs. in 100 gals. .	Power sprayer	2	0	51	6.6	92
EPN, 1% dust .	Rotary duster	2	3	64	22.1	72
Rotenone, 1% dust	Rotary duster	2	0	54	13.6	82
Garden Aerosol . .		2	0	55	19.6	82
Chlordane, 5% dust	Rotary duster	1	20	139	70.2	10
Toxaphene, 5% dust	Rotary duster	1	42	130	78.0	0
Check—no treatment		—	10	165	77.6	—

TABLE 6.—Comparative effectiveness of different spray treatments applied in summer. Applications were made June 29, 1951

Materials and Formulations	Type of Applicator	No. Infested Tips per Tree Following Treatment			Percent-age Control
		Min.	Max.	Mean	
DDT, 75 % WP, 2 3/4 lbs. in 100 gals.	Power sprayer	0	4	.9	99
DDT, 25 % Emul., 400 ml. in 3 gals.	Knapsack sprayer	5	74	25.0	75
Metacide, 1 1/2 pts. in 100 gals.	Power sprayer	0	3	.6	99
Parathion, 15 % WP, 2 lbs. in 100 gals.	Power sprayer	0	23	3.2	97
Malathion, 47 % Emul., 1 1/2 pts. in 100 gals.	Power sprayer	0	25	4.7	95
Dieldrin, 25 % WP, 6 lbs. in 100 gals.	Power sprayer	6	60	32.5	68
Check—no treatment		48	167	101.7	—

The data from these experiments (Table 8) show that in 1951 applications made between June 19 (a week before incipient hatching) and July 5 (a week after incipient hatching) reduced the population level to less than 1.5 infested tips per tree (98 to 99 percent control). The results for 1952 are similar.

TABLE 7.—Comparative effectiveness of spray treatments applied by airplane in summer. Applications were made June 29, 1951

Materials and Formulations	No. Infested Tips per Tree Following Treatment			Percentage Control
	Min.	Max.	Mean	
Parathion, 25 % Emul., 4 gals. in 100 gals.	0	26	10.7	88
DDT, 25 % Emul., 12 gals. in 100 gals.	15	82	34.6	60
Check—no treatment	32	146	86.9	—

TABLE 8.—Results of DDT applications made at intervals before and after initial hatching. Two pounds of toxicant was used per 100 gallons of water in 1951 and one pound in 1952

Dates of Application	No. Infested Tips per Tree Following Treatment			Percentage Control
	1951			
	Min.	Max.	Mean	
June 14	0	16	2.8	97
19	0	11	1.4	98
25	0	8	1.2	99
29	0	4	.8	99
July 5	0	6	1.2	99
10	2	32	8.6	89
17	5	81	28.0	66
Untreated Check	48	167	101.7	—
	1952			
June 13	1	11	5.3	69
18	0	5	1.4	92
24	0	4	.3	99
July 1	0	1	.1	99
7	0	4	.7	96
14	0	11	4 4	74
Untreated Check	5	35	17.1	—

The time in which excellent control was obtained extended over a period of 16 days. Therefore, in practice, a spray during the middle of this period (June 27 to June 30) should provide adequate control in northern Ohio even if hatching should occur a few days earlier or later than usual. Of course when it is known that a season is unusually early or late, the spray date could be varied accordingly.

RESULTS OF SPRING APPLICATIONS. In a previous section the pattern of the shoot moth's external spring activity was shown to be similar to that of its activity immediately after hatching. In 1952 and 1953 a series of sprays were applied in the early spring to determine to what degree, if any, control could be effected at this time. Friend and West (1934) perceived the possibility of control in the spring, but no experimentation by these or other workers testing this approach was found in the literature.

The more promising of the summer treatments were used in the spring experiments. Table 9 gives the details of applications and the results obtained. It is evident that the control achieved in the spring is as good or better than summer control. The same two materials, namely DDT and parathion, performed best in the spring as in the summer.

During the evaluation of the 1953 spring control treatments notes were made on the abundance of parasitized individuals in the treated area. The rate of parasitization was computed to be 2.5 percent with no appreciable difference between check trees and trees that were sprayed. All three principal shoot moth parasites were present.

Optimum Time For Spring Applications. A series of identical DDT sprays like that employed in a summer was used during two spring seasons to secure data on the optimum time in relation to resumption of larval activity for a single application to be made. Tables 10 and 11 contain data on these two series.

Applications at the two pound rate made in 1953 over a three-week period beginning April 7 (a week before incipient activity) in all cases reduced the population to an average of .7 or fewer individuals per tree (96 to 100 percent control). The 1952 results are similar in so far as they can be compared. Therefore, in northern Ohio a spray applied between April 14 and 18 should be effective unless the season is unusually early or unusually late.

The optimum timing indicated by both summer and spring series applications coincides approximately with the beginning of external larval activity. The earliest occurrence of larval caused resin exudates, therefore, is a reliable indicator for properly timing summer or spring applications.

TABLE 9.—Comparative effectiveness of different high volume spray treatments applied in spring. Applications were made April 19, 1952

Materials in 100 Gallons	No. Living Individuals per Tree Following Treatment			Percentage Control
	Min.	Max.	Mean	
DDT, 25% Emul., 1 gal.	0	0	0.0	100
Metacide, 1 ½ pts.	0	1	.1	99
Parathion, 25% Emul., 1 pt.	0	6	1.3	90
Malathion, 25% WP, 4 lbs.	0	21	6.1	55
Check—no treatment	0	32	13.5	0

TABLE 10.—Results of DDT spray applications made at intervals during resumption of larval activity in spring (1952). Sprays contained 2 pounds of toxicant per 100 gallons

Date Applied	Mean No. Resin Exudates per Tree on Application Dates*	Mean No. Living Individuals per Tree Following Treatment			Percentage Control
		Min.	Max.	Mean	
April 10	0.1	—	—	—	—
April 16	1	0	0	0	100
April 19	14	0	0	0	100
April 23	20	0	0	0	100
Check—no treatment		0	32	13.5	0

*Fifteen trees near the test plots. The figures indicate in a general way progress in the resumption of larval activity. They cannot be interpreted as a true representation of the number of larvae active at any one time because individual larvae are frequently responsible for more than one resin exudate in the spring.

TABLE 11.—Results of DDT spray applications made at intervals before and during resumption of larval activity in spring (1953)

Dates Applied	Material in 100 Gallons	No. Living Individuals per Tree Following Treatment			Percentage Control
		Min.	Max.	Mean	
April 7	1 lb.	0	0	0.0	100
	2 lbs.	0	1	.1	99
April 12	1 lb.	0	2	.6	97
	2 lbs.	0	0	.0	100
April 15	1 lb.	0	1	.1	99
	2 lbs.	0	0	.0	100
April 21	1 lb.	0	1	.5	97
	2 lbs.	0	2	.7	96
April 24	3 lbs.*	0	2	.2	99
April 28	1 lb.	0	6	2.2	87
	2 lbs.	0	2	.4	98
May 4	1 lb.	2	33	8.2	52
	2 lbs.	0	6	2.8	84
Check—no treatment		3	27	16.9	0

*Applied with a knapsack sprayer.

EFFECT OF RAINFALL ON TREATMENTS. Some rain fell during the course of each of the timing experiments. Several sprays were actually put on during light showers, and heavy rains came while some applications were still wet on the trees. In spite of the rain, however, excellent results were always obtained. Friend and Plumb (1938) stated that heavy rains may have affected several of their treatments, but some of the rainfall figures given by them are unusually large, in one instance being over 4 inches for a 24-hour period.

For purposes of record, a rain gauge was set up in the 1953 spring spray plots, and readings were made on all spray dates and at intervals throughout the remaining duration of the larval stage. A total of 6.33 inches of rain fell between the first application (April 7) and June 2, which was approximately the end of the larval period. The largest amount (.88 inch) was recorded between the third and fourth applications.

CONTROL BY REMOVAL OF INFESTED SHOOTS

Hand clipping of infested shoots has been practiced to control the shoot moth for many years. The best time in Ohio for carrying out an operation of this type is during the month of May when infested shoots are as conspicuous as they will become. The rate of shoot moth buildup which is discussed in the next section, suggests that this operation may not need to be carried out every year for maintenance of adequate control. Friend and West (1933) employed hand clipping on a large scale in forest plantations in Connecticut, and they give details on its economy and efficiency. In Christmas tree plantations it might be possible to keep the pest under control incidental to pruning or shearing operations.

FUNDAMENTAL BIOLOGICAL CONSIDERATIONS BEARING ON CONTROL PROCEDURE

Ecological investigations of the European pine shoot moth have been conducted by Butovitsch (1936), Friend and West (1933), Friend *et al.* (1938), and Brooks and Brown (1936), and ecological information appears incidentally in many other papers. Two aspects of the insect's behavior are of particular interest and importance from the control standpoint.

POPULATION BUILDUP. Injurious insects of the forest may be divided into three groups characterized by three different population types: (1) periodically eruptive populations, (2) sporadically eruptive populations, and (3) balanced populations at high density (Graham, 1939). The European pine shoot moth belongs in the last group. This type of behavior means that wherever the insect is present at all, it is currently occurring, or is destined to occur, in large numbers if not controlled by artificial means. Satisfactory natural control within the usual distributional range of the shoot moth is unknown. Also, if an infested stand has been treated mechanically or chemically and a few infested tips escaped the treatment, the population will build up in the same manner as from initial incidence. Friend *et al.* (1938) noted that the time required for equilibrium (balance population at high density) to be attained from initial incidence in red pine plantings in Connecticut is from three to five years.[8] Hawley and Lutz (1943) presented additional observations in Connecticut substantiating this factor, and the present writers have found it to apply in Ohio. The time factor in buildup has recently been employed in West Virginia (Tryon, 1951) and in Michigan (Rudolf, 1949) in recommending for red pine planting sites those areas where low temperatures lethal to wintering shoot moth larvae are supposed to occur every third to fifth year.

With a population of this type, one control operation may not be enough to insure adequate protection for as long as the stand is susceptible. Imperfect control and reinfestation will cause subsequent buildups. Therefore, inspecting the stand in alternate years following a control measure, or possibly less often, becomes a necessity. Additional control operations can then be carried out if the inspection indicates a new buildup. Periodic inspection is also advisable in previously uninfested plantings within the known range of the insect.

POPULATION DECLINE. It is a well documented fact that entry of the shoot moth into a closed, or an old stand, is not a matter for concern. The pre-closure period is the critical period in the life of the stand as regards damaging population levels. If the shoot moth population can be prevented from building up prior to closure, the insect usually will never cause significant damage, but if a moderately dense population is present by the time the trees are six feet high, serious injury may continue for some years after closure; if the population reaches equilibrium before the trees are six feet in height, there is little chance that the stand will recover (Friend *et al.,* 1938; Hawley and Lutz, 1943). In Ohio, the time required for closure to take place in red pine plantings with trees spaced at 5, 6, or 7 feet is approximately 7, 8, or 9 years respectively.[9]

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[8]Brooks and Brown (1936) reported a somewhat longer time factor in Scotch pine plantings in England.

[9]Personal communication from J. A. Gibbs, Department of Forestry, Ohio Agricultural Experiment Station.

Knowledge of the potential duration of shoot moth destructibility in a given planting, and the time factor in buildup, makes possible a clearer conception of the size and scope of the control problem. The estimated critical period in years divided by two gives the maximum number of times the planting would ordinarily need to be inspected and treated. In a stand where the critical period is 8 or 9 years, for example, probably not more than 4 inspections and treatments, and possibly fewer, would be necessary.

SUMMARY

1. The European pine shoot moth is the prime insect menace to red pine in northern Ohio. Injury is inflicted by the severing of needles and the excavation of buds and shoots thereby causing deformity. Although red pine is injured most severely, Swiss mountain and Scotch pine are attacked also.

2. Eggs are deposited during the latter half of June and the fore part of July and hatch in about nine days.

3. Newly hatched larvae wander over the shoot for several hours and then feed at the base of needles. Later they fed in buds.

4. Larvae live over winter primarily in the fourth instar and resume activity during April, when one or more new buds are attacked. Shoots are tunnelled as they develop.

5. Pupation takes place in larval tunnels during late May and early June.

6. Moths emerge primarily during the last three weeks of June.

7. Larval mortalities of 65 to 85 percent commonly occur. Extremely low winter temperatures only temporarily depress the population.

8. A number of larval parasites attack the pine shoot moth, but none have occurred in sufficient numbers to reduce the host population significantly.

9. Other moths that attack pine tips and shoots in Ohio and might be mistaken for the European pine shoot moth are: *Rhyacionia rigidana* (Fernald), *Petrova comstockiana* (Fernald), *Petrova virginiana* (Busck), *Petrova sp.* (an undescribed species), and *Dioryctria zimmermani* (Grote).

10. In control experiments carried on during four seasons, sprays appeared more effective than dusts. Best results were obtained when

sprays were applied with power ground equipment. One application of DDT at rates of one or two pounds of toxicant per 100 gallons resulted in excellent control if applied in mid April when larval activity was resumed or in late June or early July when eggs were hatching.

11. Sprays and dusts applied by airplane were inadequate.

12. Red pine plantations that grow normally reach a stage in which the European pine shoot moth is no longer a matter of concern in 7 to 9 years. The number of sprays needed to control the insect during this period may vary from one to five, depending on the efficiency of the operation and the sources of reinfestation.

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